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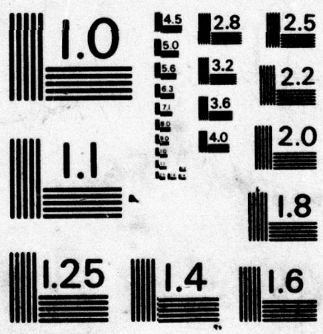

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MATERIALS RESEARCH FOR HOLOGRAPHIC RECORDING
(Report No. 1, Multiple Image Storage of
Continuous Tone Data in Volume Holograms)

JULY 1976

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This report describes tests and evaluation of 649-F plates for recording and storing multiple encoded continuous tone images for optical memories and display devices. Using this plate, up to 9 separate continuous tone images have been superimposed in a single location. Applications to graphical data storage and retrieval devices are discussed.

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PREFACE

This report was prepared under Project 4A161102B52C,Research in Geodetic, Cartographic, and Geographic Sciences.

This report describes the results of an in-house program in materials research at the U.S. Army Engineer Topographic Laboratories for applications of holography to the field of mapping. Subsequent reports will deal with a variety of specific aspects such as bleaching, dimensional stability of materials, developers.

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ILLUSTRATIONS

TABLES

MATERIALS RESEARCH FOR HOLOGRAPHIC RECORDING.
Report No. 1, Multiple Image Storage of Continuous
Tone Data in Volume Holograms.

__RESEARCH OBJECTIVES AND RATIONALE__. A research program is currently in process at the U.S. Army Engineer Topographic Laboratories (ETL) to develop and apply methodology for studies of the applications of holography to the acquiring, processing, interpreting, and displaying of topographic information. Although the state-of-the-art in holographic recording materials is advancing rapidly, data and results appearing in the literature are often concerned with very specific or limited applications. Consequently, the results and conclusions obtained under certain conditions or for particular applications can rarely be directly transferred or applied to other situations. For this reason, an in-house capability in materials research at ETL was considered necessary to support such applications as holographic mass memories, holographic optical elements, and holographic terrain displays; all of which have been investigated at ETL. Work has concentrated on the recording materials, i.e. the light sensitive substances, and also the processing materials and techniques, such as developers, bleaches, special baths, and drying procedures. For all phases of the work, particular attention is given to operational requirements for map and photographic storage and retrieval.

The research program is expected to result in a number of reports on various aspects of holography as applied to mapping and data display. This first report describes experimental studies concerning the superimposition of multiple holographic images in Kodak 649-F emulsion.

__INTRODUCTION__. The storing and rapid accessing of information such as maps, charts, and other graphic data is becoming expensive and difficult because of the sheer volume of such material. An estimate of the Defense Mappir : Agency Topographic Center's (DMATC) Department of Technical Services is that they store approximately 180,000 sets of map reproduction materials, with each set consisting of approximately 20 pieces of copy for each map. Consequently, from these figures DMATC could be storing as many as 3,600,000 items for map reproduction. The space and equipment required to store and retrieve such a volume of data for processing or displaying represents a great investment in manpower and energy.

In the past, attempts have been made to reduce storage requirements by using microfilm. However, as the volume of data increases and the need to store at very high densities becomes necessary, a number of problems arise with microfilm storage and retrieval devices. The problems include a requirement for great precision in readout optics, the need for storage materials with essentially no surface

defects, and the need for careful handling of the stored data since dust and scratches may easily obscure portions of the recording.

Holographic storage and retrieval techniques, however, offer the possibility of storing graphical data at high densities and of accessing the data without many of the problems inherent in conventional optical systems. Nelson, Vanderlugt, and Zech,[1] for example, have described a storage and retrieval system based on holographic techniques that reconstructs up to 60 pages of digital data in human or machine readable form on a single microfiche sheet. In addition, it has been known for some time that storage capacity can be increased by superimposing holograms in a three-dimensional storage medium. To superimpose holograms, either the reference beam angle or the laser wavelength is varied from one hologram to the next at the same storage location. Images are individually reconstructed by illumination of the hologram with a reconstruction beam corresponding in direction and wavelength to the original reference beam.

The purpose of this report is to describe the test and evaluation of the Kodak 649-F plate for recording and storing multiple encoded continuous tone images for optical memories and display devices. Using this plate, up to nine separate continuous tone images have been superimposed in a single location. After describing the techniques for recording multiple images, the report discusses the data and results in terms of their application in data storage devices.

Additional information is available from the references on the applications of coherent optics and holography in mapping and data storage.[2, 3]

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[1]R. J. Nelson, A. Vanderlugt, and R. G. Zech, "Holographic Data Storage and Retrieval," Proceedings SPIE, Vol. 45, March 1974, pp. 161-167.

[2]N. Balasubramanian and R. D. Leighty (Eds.), "Coherent Optics in Mapping," Proceedings SPIE, Vol. 45, March 1974.

[3]L. d'Auria, J. P. Huignard, C. Slezak, and E. Spitz, "Experimental Holographic Read-Write Memory Using 3-D Storage," Applied Optics, Vol. 13, April 1974, p. 808.

NATURE OF INFORMATION STORAGE IN VOLUME HOLOGRAMS. Volume holograms can be regarded as superpositions of three-dimensional diffraction gratings; the diffraction of which can be described in terms of the Bragg relationship:

$$2d \sin \frac{\theta_{IB}}{2} = \lambda$$

In this equation, d is the spacing of a set of parallel fringes on which all scattering centers of the grating are distributed, θ_{IB} is the angle between the light beams used to construct the hologram (figure 1), and λ is the wavelength of the light used.

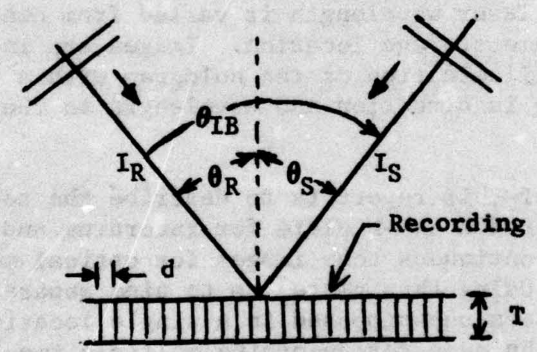

Figure 1. Recording of Holographic Grating.

Formation of such a hologram is shown schematically in the above figure. Two plane waves labeled I_R and I_S represent the reference and signal beams, respectively, and are oriented ($\theta_R = \theta_S$) so that the interference fringe planes are formed perpendicular to the surface of the recording medium. The incidence angles of the reference and signal beams with respect to the normal to the hologram plane are denoted by θ_R and θ_S, respectively. If the thickness, T, of the recording medium is large compared to the fringe spacing, d, the hologram exhibits so-called volume properties.

A distinctive property of holograms recorded in relatively thick recording media is that their diffraction intensity is highly sensitive to both the wavelength and direction of incidence of the recording and reconstructing beams. Both of these parameters, therefore, can be effectively used to construct a hologram so as to store a number of different images in the same area of the recording medium. The more convenient technique is to vary the incidence angle of the illumination beams between each exposure while maintaining the wavelength constant. In the readout or reconstruction process, the hologram is rotated in the illuminating light beam; whereupon, each image is generated without interference from the other recordings.

Holograms are initially formed in photographic emulsions as spatial distributions of finely divided elemental silver. These absorption holograms are limited to diffraction efficiencies of only a few percent. By chemical bleaching the photographic emulsions, the absorption holograms are converted into phase holograms with high potential diffraction efficiencies. As a result of the bleaching process, the opaque silver grains are converted into a transparent silver salt, such as silver bromide. The silver salt particles have a high refractive index relative to the gelatin so that there is a differential in the net refractive index where there is a differential in the concentration of the silver salt. This variation in refractive index forms the phase hologram.

<u>EXPERIMENTAL SECTION</u>. The three-dimensional data storage capability of volume holograms and the relative simplicity of information recovery is of particular interest to the mapping community. One area of interest is map storage devices, which provide a good example of the application of volume holograms for optical memories. Theoretically, a large number of map data sheets can be superimposed in a common area of a photographic plate or other detector material. Upon proper illumination of the hologram, each recorded image may be individually reconstructed and projected onto a screen for a large-field display. Since the stored information is distributed throughout the entire thickness or volume of the recording material rather than being localized on the surface, a reduction in the number of film chips or plates is achieved.

The following sections describe the testing and evaluation of a particular recording material, Kodak 649-F photographic emulsion, as a potential candidate for use in a holographic map storage device.

<u>Input Imagery</u>. In order to approximate continuous imagery that might be stored in a holographic storage and retrieval device and to make quantitative measurements on image quality, a test target consisting of a step-wedge of four density levels mounted on a ground glass diffuser was prepared (figure 2). The target measured 2.5 centimeters on a diagonal and was positioned 16 centimeters from the recording plane.

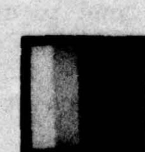

Figure 2. Input Test Target

Relative percent transmissions of the steps were determined from the relative intensity values of a narrow beam of laser light before and after transmission through the target and were in the ratio 1 :0.47 :0.23 :0.11.

Optical Arrangement, The Fresnel Hologram. The optical arrangement, which is mounted on a vibration isolated table, is illustrated in figure 3. Light from the laser (Spectra-physics model 125, He-Ne, located beneath the table), after being expanded and collimated, is split into two paths by the beam splitter and subsequently directed by the mirrors to the recording plane. The target is inserted in one path referred to as I_S in figure 3. The result is that two wavefronts, one a plane reference wave, I_R, and the other the diffracted wave, I_S, interfere at the recording plane to form the hologram.

Holograms recorded with the above combination of target and optical arrangement are called Fresnel holograms. One important aspect of this type of hologram, in regard to superimposing multiple images, is the much smaller dynamic range required of the recording material. Since the signal beam passes through a diffuser, the range of intensities at the hologram is less, and more images can be recorded before saturation is reached.

In the present report, holograms were recorded at a constant interbeam angle, $\theta_{IB} = 47.7^{\circ}$ for various angular orientations of the photographic plate with respect to the light beams. Plate orientation was adjusted by means of a rotatable platform provided with an angular vernier scale. During reconstruction, only the reference beam I_R was incident on the emulsion. Intensities of the first order diffracted beam were measured with a photomultiplier.

Chemical Processing. After exposure, the hologram is removed from the optical system for development and chemical processing (see tables 1 and 2). The first step, development, is the critical operation. For consistent repeatable results, development time and temperature must be carefully controlled. Each of the other steps permit variation in time of approximately 20 percent. It is important, however, to maintain each bath at the same temperature to within a few degrees to avoid gelation reticulation.

Environmental conditions tend to modify the characteristics of most emulsions. Extreme high temperatures can cause fogging, low temperatures reduce exposure sensitivity, and excessive humidity causes swelling and hypersensitization. Colburn et al.[4] recommend that for recording

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[4]W. S. Colburn, R. G. Zech, and L. M. Ralston, "Holographic Optical Elements," Technical Report AFAL-TR-72-409, Wright-Patterson Air Force Base, Ohio, January 1973.

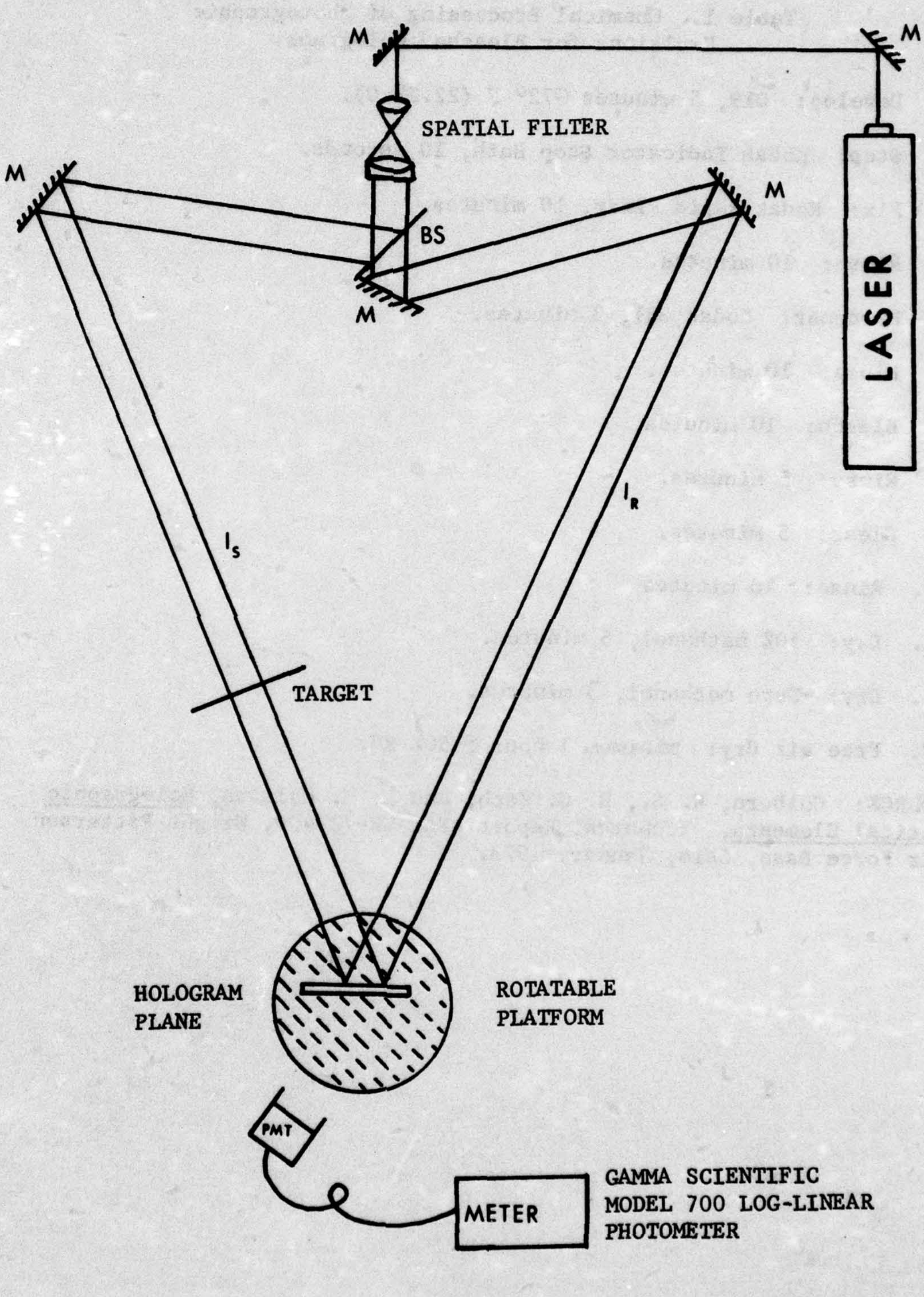

Fig. 3 Optical Arrangement

Table 1. Chemical Processing of Photographic Emulsions for Bleached Holograms.

1. Develop: D19, 5 minutes @72° F (22.2° C).

2. Stop: Kodak Indicator Stop Bath, 20 seconds.

3. Fix: Kodak Rapid Fixer, 10 minutes.

4. Rinse: 10 minutes.

5. Hardener: Kodak SH1, 3 minutes.

6. Rinse: 10 minutes.

7. Bleach: 10 minutes.

8. Rinse: 5 minutes.

9. Clear: 5 minutes.

10. Rinse: 10 minutes.

11. Dry: 50% methanol, 5 minutes.

12. Dry: Pure methanol, 3 minutes.

13. Free air dry: minimum 1 hour @ 50% RH.

SOURCE: Colburn, W. S., R. G. Zech, and L. M. Ralston, Holographic Optical Elements, Technical Report AFAL-TR-72-409, Wright-Patterson Air Force Base, Ohio, January 1973.

Table 2. Preparation of Bleach and Clearing Bath

BLEACH

1. Dissolve 25 grams $FeCl_3$ in 500 ml distilled water.

2. Add and dissolve 25 grams $CuBr_2$.

3. Carefully add 10 ml concentrated H_2SO_4 with stirring.

4. If the color of the solution is a brilliant emerald green, add distilled water to make 1 liter of solution. Up to 10 additional ml of acid may be added to develop a bright green color.

5. Filter the solution to remove any cloudy particulate matter.

6. Discard the bleach solution following use. Do not return used bleach to the original container.

CLEARING BATH

Solution A: Dissolve 5 grams potassium permanganate ($KMnO_4$) in one liter distilled water.

Solution B:
1. Dissolve 50 grams potassium bromide (KBr) in 500 ml distilled water.
2. Carefully add 10 ml concentrated H_2SO_4.
3. Add distilled water to make 1 liter of solution.

Just before use, add one part of Solution A to 10 parts of Solution B.

Discard after use.

SOURCE: Colburn, W. S., R. G. Zech, and L. M. Ralston, Holographic Optical Elements, Technical Report AFAL-TR-72-409, Wright-Patterson Air Force Base, Ohio, January 1973.

holograms the temperature and relative humidity should be maintained from 60 to 80° F (15.5 to 26.6° C) and 30 to 60 percent, respectively. In the laboratory in which the present work was conducted, temperatures ranged between 68 and 80° F (20 to 26.6° C). Relative humidities, however, were on the high side, exceeding 65 percent on some occasions. However, if hologram recording and reconstructing are both performed at the same temperature and relative humidity, adverse effects on image quality should be minimal.

The diffraction efficiencies of the absorption holograms initially recorded are increased significantly by chemical bleaching (from a few percent to about 50 to 60 percent). A number of bleaching agents and processes are described in the references.[5, 6] Each agent and process has advantages and limitations. The process used in the present work is that of Colburn et al.[7] and was found to give very good results.

Multiple Image Storage by Angular Encoding. In order to independently superimpose a sequence of images by incrementally changing the angular orientation of the recording material between each exposure, the chosen angular increment must be sufficiently large to avoid crosstalk between successive images. In this report, it was determined experimentally that an increment of 10° is required for crosstalk elimination in photographic plates with an emulsion thickness of 15 μm (micrometers). A series of multiply exposed plates was made with various angular separations between exposures. Exposures with angular separations less than 10° producted ghost images of adjacent exposures (figure 4). At greater than 10° angular separation, however, each image was distinct with no apparent interference from neighboring exposures.

Figure 4. Ghost Images.

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[5]A. Graube, "Advances in Bleaching Methods for Photographically Recorded Holograms," Applied Optics, Vol. 13, No. 12, December 1974, p. 2942.

[6]J. Upatnieks and C. Leonard, "Diffraction Efficiencies of Bleached, Photographically Recorded Interference Patterns," Applied Optics, Vol. 8, No. 1, January 1969, p. 85.

[7]W. S. Colburn, R. G. Zech, and L. M. Ralston, "Holographic Optical Elements," Technical Report AFAL-TR-72-409, Wright-Patterson Air Force Base, Ohio, January 1973.

To evaluate the potential of Kodak 649-F plates for superimposing continuous tone images, a series of plates containing from one to nine encoded holographic images of the test target was prepared (figures 5 to 11). These images were encoded at 10^{o} angular separations, and after each exposure, the input target was rotated 90^{o} (step bars either horizontal or vertical) to distinguish between successive exposures and to aid in detecting any ghost images that might be present.

A maximum of 18 images could be stored on a plate using 10^{o} angular separations between recordings. In practice, however, the number of images that can be stored is limited by the dynamic range of the emulsion. The total exposure must be kept below the saturation point to avoid a loss of information. Therefore, as the number of recordings in a sequence increase, the individual exposures must decrease. This means that the diffraction efficiency of each hologram can become extremely low. In figures 9 through 11 where more than three encoded images are superimposed, the reconstructions become very weak.

The main criterion used for judging the potential of the 649-F emulsion for storing multiple continuous tone images was the fidelity with which density ratios of the original test target were preserved in the reconstructed images. This is an empirical evaluation, which assumes that all degrading influences such as limited dynamic range, noise, etc. will be reflected in the resulting reconstructed image quality. Density ratios of the reconstructed images were determined by focusing the images onto a ground glass screen and measuring the relative brightness of each step with the aid of a small diameter fiber optic probe and photomultiplier.

In table 3, the relative birghtness data are presented for the original test target and reconstructed images from a series of plates containing from one to nine superimposed holograms. For each image, the relative brightness of the first step was normalized to a value of 1.0. The brightness ratios of the image reconstructed from a hologram with a single recording (1 :0.49 :0.23 :0.09, figure 6) correspond closely with those of the original (1 :0.47 :0.23 :0.11, figure 5). Also, the brightness ratios of the two-exposure hologram (figure 7) approximate those of the original image, although the second exposure (figure 7b) has begun to deviate somewhat in the higher densities. However, as is evident from the results shown in figures 8 through 11, both the signal-to-noise ratio and the image contrast begin to degrade significantly for holograms with three or more superimposed images, although in no case were images obliterated.

<u>Signal-to-Noise Ratio Measurements</u>. Although measured signal-to-noise ratios (SNR) of holograms usually depend on the nature of the input signal or target, the results of measurements made on several superimposed plane-wave gratings lead to similar conclusions regarding

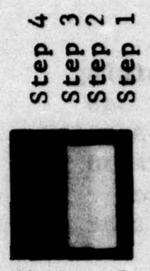


Figure 5. Original

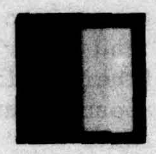


Figure 6. Reconstruction from a single exposure hologram.

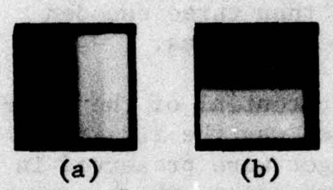


Figure 7. Reconstructed images from a multiple exposure hologram of two recordings.

Figure 8. Reconstructed images from a multiple exposure hologram of three recordings.

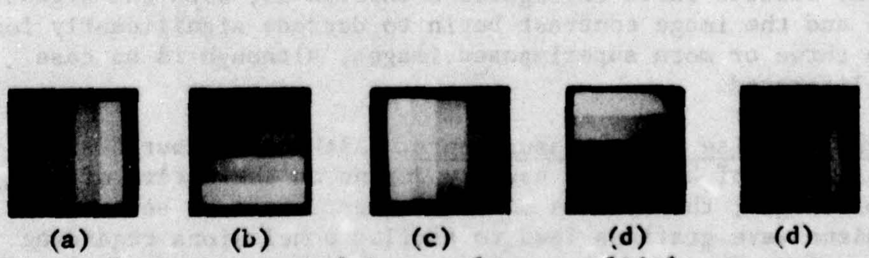
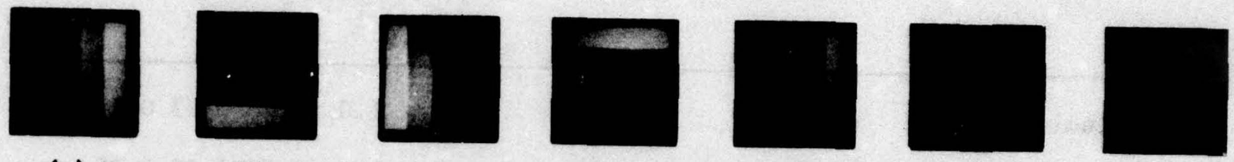
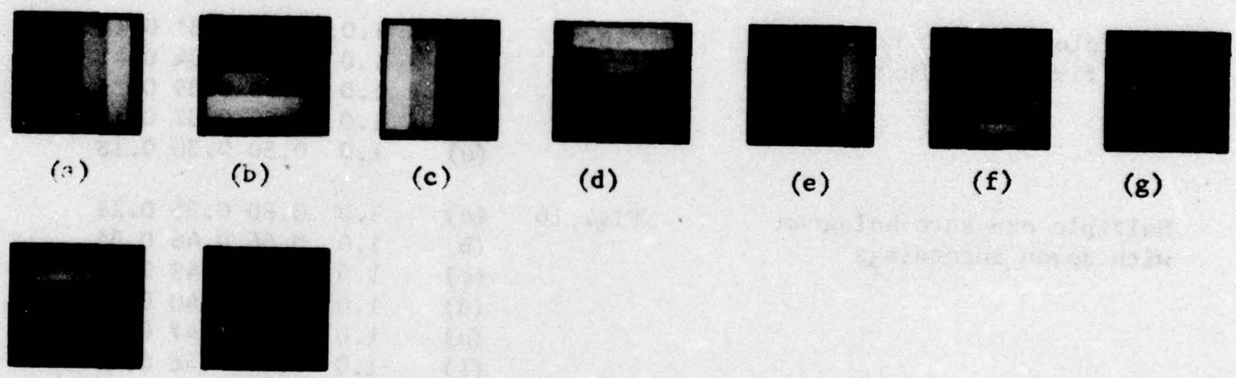


Figure 9. Reconstructed images from a multiple exposure hologram of five recordings.



(a) (b) (c) (d) (e) (f) (g)

Figure 10. Reconstructed images from a multiple exposure hologram of seven recordings.



(a) (b) (c) (d) (e) (f) (g)

(h) (i)

Figure 11. Reconstructed images from a multiple exposure hologram of nine recordings.

Table 3. Relative Brightness Data for Reconstructed Step-Wedges

			Step			
			1	2	3	4
Original	Fig. 5		1.0	0.47	0.23	0.11
Single exposure hologram	Fig. 6		1.0	0.49	0.23	0.09
Multiple exposure hologram with two recordings	Fig. 7	(a)	1.0	0.50	0.24	0.11
		(b)	1.0	0.53	0.30	0.17
Multiple exposure hologram with three recordings	Fig. 8	(a)	1.0	0.48	0.24	0.14
		(b)	1.0	0.50	0.27	0.23
		(c)	1.0	0.66	0.40	0.30
Multiple exposure hologram with five recordings	Fig. 9	(a)	1.0	0.58	0.31	0.18
		(b)	1.0	0.57	0.34	0.41
		(c)	1.0	0.60	0.39	0.21
		(d)	1.0	0.56	0.32	0.19
		(e)	1.0	0.50	0.30	0.18
Multiple exposure hologram with seven recordings	Fig. 10	(a)	1.0	0.60	0.36	0.21
		(b)	1.0	0.66	0.46	0.34
		(c)	1.0	0.65	0.48	0.31
		(d)	1.0	0.61	0.40	0.26
		(e)	1.0	0.66	0.47	0.32
		(f)	1.0	0.66	0.46	0.38
		(g)	1.0	0.74	0.54	0.36
Multiple exposure hologram with nine recordings	Fig. 11	(a)	1.0	0.60	0.35	0.19
		(b)	1.0	0.65	0.42	0.25
		(c)	1.0	0.59	0.34	0.19
		(d)	1.0	0.68	0.41	0.27
		(e)	1.0	0.73	0.51	0.33
		(f)	1.0	0.65	0.35	0.34
		(g)	1.0	0.70	0.47	0.27
		(h)	1.0	0.73	0.47	0.27
		(i)	1.0	0.71	0.49	0.28

multiply exposed holograms as do the tests with the step tablet. The fidelity of reconstructed images drops markedly with more than three exposures. Relatively high SNR's were observed for a singly exposed hologram and for two superimposed images. However, for three or more superimposed holograms, the SNR's dropped to very low values.

Measurements were made using the optical system shown in figure 12. The first diffracted order was imaged by lens L onto a photomultiplier at P. With all the first order diffracted light falling on the photomultiplier, a reading proportional to signal plus noise (S+N) is obtained. With a knife-edge, KE, positioned so as to just block all the unscattered light and one-half of the scattered light, a reading proportional to one-half the noise, N, is obtained. From these measurements, signal-to-noise ratios were calculated. Table 4 lists the SNR data measured on plates with from one to three superimposed images.

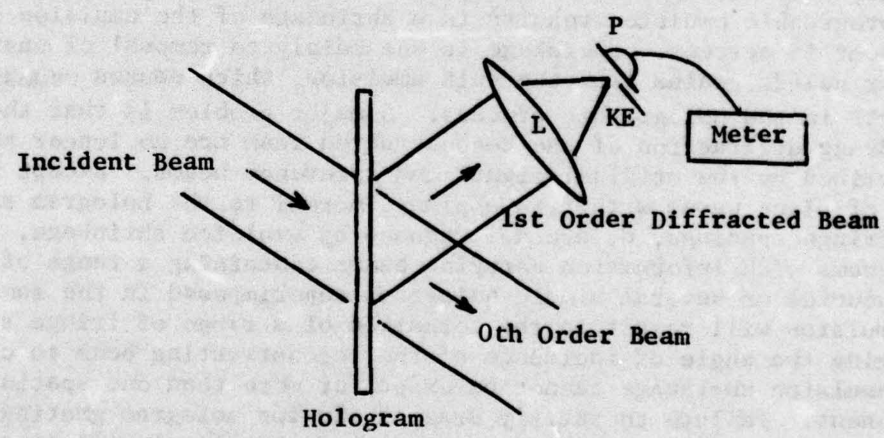


Figure 12. Diagram of Setup for Signal-to-Noise Ratio Measurements.

Table 4. Signal-to-Noise Ratio Measurements.

No. Superimposed Holograms	SNR 1st recording	2nd recording	3rd recording
One	105.0	-	-
Two	85.0	58.0	-
Three	3.4	2.9	3.5

DISCUSSION. Signal-to-noise ratios and the data from the test-target reconstructions indicate that about two continuous tone images can be superimposed and retrieved with good image fidelity from 17 μm thick 649-F emulsions. This represents a low storage capacity. However, Leith and Upatnieks[8] concluded that continuous tone transparencies are fully an order of magnitude more difficult to reconstruct than simple objects like lettering or other binary information. Broad uniform image areas are the most difficult portions of continuous tone imagery to reconstruct. These will appear mottled in the reconstructions unless considerable care is taken; therefore, the holograms must be extremely clean and free from scratches.

Dynamic range factors combined with a variety of noise-producing effects interact in a complex manner to degrade the quality of reconstructed holographic images. Image quality is usually highly sensitive to even small imperfections in materials or processing. Burckhardt[9] has shown that even the low level of noise in 649-F emulsion reduced the data storage capacity of a holographic character recognition filter by two orders of magnitude compared with that of a hypothetical noiseless recording medium. Processing the recording medium after exposure is the primary producer of noise. The process of developing, fixing, bleaching a photographic emulsion results in a shrinkage of the emulsion thickness by about 15 percent. Shrinkage is due mainly to removal of unexposed silver halide grains from the bulk emulsion, which causes undesirable effects in the holographic process. A major problem is that the conditions for Bragg diffraction of the reconstructed beam are no longer those determined by the original signal and reference beams. Except in the case of plane waves with fringe planes normal to the hologram surface, the fringe spacings, d, are all reduced by emulsion shrinkage. Non-simple holograms with information carrying beams containing a range of spatial frequencies or several simple holograms superimposed in the same area of an emulsion will result in the formation of a range of fringe spacings. Changing the angle of incidence of the reconstructing beam to compensate for emulsion shrinkage cannot be exact for more than one spatial frequency component. Failure to satisfy Bragg's law for hologram grating components formed by the other spatial frequencies of the signal will cause attenuation, distortion, and loss of resolution in the reconstruction.

Another noise-producing factor is stress formation during the drying of the emulsion. A drying boundary across the surface of the emulsion usually accompanies normal drying of an emulsion after the final wash.

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[8] E. N. Leith and J. Upatnieks, "Wavefront Reconstruction with Continuous Tone Objects," Journal of the Optical Society of America, Vol. 53, December 1963, p. 1377.

[9] C. B. Burckhardt, "Storage Capacity of an Optically Formed Spatial Filter for Character Recognition," Applied Optics, Vol. 6, No. 8, August 1967, p. 1359.

The migration of silver halide grains in the immediate vicinity of the boundary results from stresses existing across the boundary. Further, the slow migration of this boundary across the emulsion surface gives rise to a build-up of nonuniform stress in the drying emulsion and results in reticulation of the emulsion surface.

Since to be efficient in a data storage and retrieval device a material should be capable of superimposing a large number of images, silver halide materials that have a certain amount of granularity and require wet chemical processing do not appear suitable for high density holographic storage. However, as is indicated in the following section, a number of other materials appear considerably more promising in this area.

SUMMARY AND CONCLUSION. A method for storing continuous tone photographs has been studied which is straightforward in concept and experimentally easy to implement. The basic criteria for evaluation of any image encoding scheme are storage capacity and crosstalk levels. Although the 17 μm thick, 649-F emulsion studied in this research does not appear to have significant potential for holographic storage of continuous tone data, it appears probably that one or more other recording materials may provide a useful image storage capacity.

By taking advantage of its angular selectivity for the illuminating beam, a thick, volume-type hologram can store large amounts of information in a limited area. As for the maximum storage density of a volume-type hologram memory, the following conclusions have been stated in the literature.[10, 11]

In an ideal (noise-free) thick hologram, the theoretical storage capacity is proportional to the thickness of the hologram. In actual hologram memories in which optical noise is present owing to the microscopic granularity in the hologram, the storage capacity is proportional to the square root of the number of photo-sensitive particles in a unit area.

According to either of these statements, any amount of information can be stored in a hologram of sufficient thickness. Although this is not a practical conclusion, since in such a case the noise will become intolerably large, compromises in the selection of materials may be made between acceptable noise levels and the number of images stored.

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[10] P. J. Van Heerden, "Theory of Optical Information Storage in Solids," Applied Optics, Vol. 2, No. 2, April 1963, p. 393.

[11] V. V. Aristov, "Optical Memory of 3-Dimensional Holograms," Optics Communications, Vol. 3, March 1971, p. 194.

The use of recording materials other than silver halides offer considerable benefit for producing low-noise, high-storage-capacity holograms. One source of noise inherent in silver halide emulsions, which the use of other materials would eliminate, is the so-called film-grain noise arising from the particulate nature of the silver halide. Holograms recorded in dichromated gelatin have very good optical qualities. Diffraction efficiencies can approach 100 percent and noise levels are low. Photochromic materials appear to also have potential. Holograms recorded in these materials have no grains, require no development, and can be reused after thermal or optical erasure.

Perhaps the most promising materials yet investigated for use as a 3-D optical memory are the ferroelectric type materials. The refractive index change under the action of light in such crystals has been noted by Ashkin[12] and the use of this effect for the storage of phase holograms has been shown by Chen et al.[13]

These various materials, the thickness of which are several millimeters, are compatible with the superimposition of holographic images by angular encoding techniques. Investigations of these materials for their potential in storage and retrieval devices will be described in a subsequent report.

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[12] A. Ashkin, "Optically Induced Refractive Index Inhomogeneities in $LiNbO_3$ and $LiTaO_3$," Applied Physics Letters, Vol. 9, July 1966, p. 72.

[13] F. S. Chen, J. T. Lamacchia, D. B. Fraser, "Holographic Storage in $LiNbO_3$," Applied Physics Letters, Vol. 13, October 1968, p. 223.